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ABSTRACT

We propose a distribution function for multiplicity in accordance with the stochastic number evolution. This function gives a universal description of inelastic and nondiffractive multiplicity distributions in pp collisions at 250, 360 and 800 GeV/c. The negative binomial distribution fails in the description of inelastic data.

АННОТАЦИЯ

Предлагается распределение по множественности в соответствии с эволюцией стохастического числа. Это распределение дает универсальное описание как неупругого, так и недифракционного распределений по множественности в pp взаимодействиях при 250, 360 и 800 ГэВ/с. Отрицательное биномиальное распределение не описывает неупругих данных.

KIVONAT

Olyan multiplicitás eloszlást javasolunk, amely összhangban van a stohasztikus szám kialakulással. Ez az eloszlás univerzálisan leirja mind az inelasztikus, mind a nondiffractiv multiplicitás eloszlásokat 250, 360 és 800 GeV-s pp ütközések esetén. A negativ binomiális eloszlás nem alkalmas az inelasztikus adatok leirására.

Experimental data on the inelastic multiplicity distribution of charged particles produced in pp collisions at Serpukhov, FNAL [1] ISR energies [2] and in e^+e^- annihilations at PETRA energies [3], as well as in hadron ($\pi^-, K^-, \bar{p}$) - nucleus (Li, C, S, Cu, CsI, Pb) interactions at 40 GeV for negative particles [4] can be well described by the distribution [5,7,4]

$$P_n = \frac{2m}{\langle n\rangle \Gamma(A_m)} F^{A_m}(A_m) \left(\frac{n}{\langle n\rangle}\right)^{mA_m-1} \exp\left[-F(A_m)\left(\frac{n}{\langle n\rangle}\right)^m\right] \tag{1}$$

where

$$F(A_m) = \frac{\Gamma^m(A_m+1/m)}{\Gamma^m(A_m)}$$, and Γ is the gamma function.

The two parameters $A_m(s)$ and $\langle n\rangle$ are related to the dispersion $D=(\langle n^2\rangle-\langle n\rangle^2)^{1/2}$ by

$$\frac{D^2}{\langle n\rangle^2} = \frac{\Gamma(A_m+2/m)}{\Gamma^2(A_m+1/m)}\Gamma(A_m) - 1$$

and m is a real positive number, which is independent of energy. The scaled moments are as follows:

$$C_L \equiv \frac{\langle n^L\rangle}{\langle n\rangle^L} = \frac{\Gamma(A_m+L/m)}{\Gamma^L(A_m+1/m)}\Gamma^{L-1}(A_m) \tag{2}$$

One can see that

$$\langle n\rangle P_n \equiv \psi\left(z=\frac{n}{\langle n\rangle}, s\right)$$

has KNO scaling behaviour ($\psi(z,s)\to\psi(z)$ or c_L=constant for every L, when $s\to\infty$) if A_m tends to a constant value, when the energy goes to infinity. Thus A_m is the scaling violation parameter.

The analitical form of formula (1) was determined by the generalization of the constraint method [5,6]. It is remarkable that the stochastic number evolution [8] is also in accordance with the formula (1).

The evolution for some class of models is given by the Langevin equation for multiplicative noise [8].

$$(3) \qquad \frac{dz}{dt} = \dot{z} = az - bz^{1+\gamma} + zf(t) \ .$$

The parameters (a, b, γ) can be identified with parameters in the fundamental Hamiltonian of the system: $\langle f(t)f(t')\rangle = Q\delta(t-t')$ where Q is the noise strength. We want to emphasize that formula (3) can be applied to various fields such as nonlinear optics (subharmonic generation, parametric tree-wave mixing), autocatalic chemical reactions, population dynamics and so on [9].

In the case of Gaussian white noise the equation (3) is stochastically equivalent to the Fokker-Planck equation having the steady-state solution [9]

$$(4) \qquad \psi(z) = Nz^{(-1+2a/Q)} \exp\left[-\frac{2b}{Q}\frac{z^{\gamma}}{\gamma}\right]$$

where N is the normalization constant.
Comparing equations (1) and (4), we can see that

$$\frac{2b}{\gamma Q} = F(A_m), \quad \frac{2a}{Q} = mA_m \quad \text{and } \gamma = m$$

Thus the number m is characterising the nonlinearity of equation (3). We should mention that a sketch of a generalization of a geometric-optical model is given in ref. [7]. This model uses a new reasonable eikonal leading to the formula (1) too.

New data on the inelastic multiplicity distribution of charged particles produced in pp collisions at 250, 360 and 800 GeV/c have recently been published [10,11,12]. The data were obtained from CERN and FNAL fixed target experiments. Because of the bubble chamber technique, systematic errors are kept to a minimum [10,11,12].

The inelastic cross sections for the production of n charged particles σ_n-s are presented at each energy. Taking σ_n-s from a given threshold n_{th} ($n_{th} \geq 8$ at 800 and 360 GeV/c and $n_{th} \geq 6$ at 250 GeV/c) we can determine the nondiffractive multiplicity distribution

$$P_n^{(n.d)} = \frac{\sigma_T^{(in.)}}{\sigma_T^{(n.d)}} P_n^{(in.)} \ , \text{ or } RP_n^{(n.d)} = P_n^{(in.)} \ ,$$

where R is the ratio of the total cross sections and this

ratio is a constant value at a given energy. The negative binomial (or Pólya) distribution can be well fitted to the nondiffractive data (for n_{ch}.n) [10,12]. In table 1 the sign * denotes these published results.
Using the MINUIT program, a fitting procedure was carried out. The three parameters (<n>,R,A) of the distribution (1)

$$RP_n^{(n.d)}(\langle n\rangle^{(n.d)}, A_m=A^{(n.d)}, m=5/4)=$$

$$=P_n^{(in.)}(\langle n\rangle^{(in.)}, A_m=A^{(in.)}, m=2), \text{ for } n.n_{ch}$$

and the errors of parameters, as well the χ^2 value were obtained as a results of the full MINUS error analysis. Paraboiic error were taken, and in the ERROR DEF procedure the parameter Up=3.67 was used. These results were the same as those of HESSE procedure. The fit parameters are collected in table 1 together with the χ^2 value at each energy. We can see that the two distribution give similar χ^2 values and the average values are in good agreement within the errors. Parameter A is varying slowly in this energy range.
The parameter R is constant within the errors, and the value of R is in excellent agreement with the observed value R=0.88 at 1000 GeV/c [13] ($s^{1/2}$=44.5)
Lately the negative binomial distribution has been studied [14] for the inelastic data. A fit of parameter A and k was carried out to experimental data, while <n> was taken from experiment. From table 2 we can see the results of fits. As can be seen from this table the agreement with experiments are reasonable for the proposed distribution (1), and the negative binomial distribution proves to be completly bad for the inelastic data. The very large χ^2 value is taken from ref. [10] at 250 GeV/c. These results are contrary to the conclusion mentioned in ref. [14].
The value of the parameter A is about 1. When A_m=1, the distribution (1) reduces to the Weibull distribution. By varying A and m a number of distributions can be obtained as a special case of the proposed distribution (1).
(A=k and m=1 gives the asymptotic KNO function of the negative binomial distribution).
Substituting the fitted A in equation (2) we can calculate the scaled moments. The results are presented in table (3) and (4). We can see that all calculated scaled moments are in excellent agreement with the observed values of c for inelastic interactions (m=2). The observed values at 800 GeV/c are taken from ref. [12].
The important point to emphasize is that the choise m=2

gives exellent results for inelastic interactions not only in this 250-800 GeV energy range, but also in the 50-2100 GeV interval [5]. The calculated scaled moments for nondiffractive ($m=5/4$) interactions can be found in table (3). It can be seen that the published results at 1000 GeV [13] are very similar to the calculated results at 800 GeV.

We want to emphasize that formula (2) for c has only 1 parameter A depending on the energy, and the analitical form of this formula is simple for every L.
The scaled moment of the negative binomial disttribution has two parameters (k and $\langle n \rangle$) depending on energy and the anallitical form is very complicated for higher L.
The energy dependence of parameters $\langle n \rangle$ and A_m is on an empirical level. Nevertheless good zero parameter empirical description is presented in ref. [7] for inelastic pp interactions in the 50-2100 GeV energy range.
The trend of the $A^{(n.d)}$ parameter is more sophisticated because $A^{(n.d)}$ is decreasing at Sp$\bar{p}$S energies.
We conclude that the proposed distribution (1) gives a reasonable description not only for inelastic pp multiplicity distributions, but also for nondiffractive distributions while the negativ binomial distribution can be only used for nondiffractive case.

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Table 1

Parameters and X^2/NF values of nondiffractive distribution fits

GeV	Equation (1)				Negative Binomial			
	<n>	R	A	X^2/NF	X^2/NF	k	R	<n>
800	11.20 ±0.23	0.87 ±0.03	3.41 ±0.27	5.4/9	5.4/8*	8.5* ±0.3	-	11.00* ±0.10
360	9.74 ±0.34	0.89 ±0.06	3.36 ±0.42	7.6/6	7.6/6	9.28 ±0.81	0.93 ±0.08	9.50 ±0.21
250	8.66 ±0.27	0.86 ±0.05	3.20 ±0.36	13.6/8	9.1/9*	(0.084* ±0.013)+	-	8.84* ±0.19

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Table 2

Parameters and X^2/NF values of inelastic distribution fits

GeV	$\langle n \rangle_{exp}$	Equation (1)		Negative Binomial	
		A	X^2/NF	X^2/NF	k
800	10.26 ±0.15	1.04 ±0.02	16.1/14	56.3/14	6.11
360	9.06 ±0.09	1.08 ±0.02	9.8/11	24.2/11	7.22
250	7.88 ±0.02	0.98 ±0.02	15.3/12	38.6/12*	6.45*

Table 3

Nondiffractive scaled moments

GeV	A	C_2	C_3	C_4	C_5
1000	-	(1.19±0.01)*	(1.62±0.02)*	(2.49±0.06)*	(4.2±0.2)*
800	3.41	1.19	1.63	2.52	4.36
360	3.36	1.19	1.64	2.55	4.40
250	3.20	1.20	1.68	2.65	4.67

Table 4

Inelastic scaled moments

GeV	A	C_2	C_3	C_4	C_5
800	1.04	1.26 (1.26±0.01)*	1.86 (1.85±0.05)*	3.11 (3.09±0.12)*	5.73 (5.64±0.08)
360	1.08	1.25 (1.25±0.02)	1.83 (1.81±0.04)	3.02 (2.97±0.09)	5.48 (5.35±0.19)
250	0.98	1.29 (1.27±0.03)	1.96 (1.91±0.05)	3.38 (3.27±0.12)	6.45 (6.20±0.32)

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